DEPARTMENT OF COMMERCE
SINCLAIR WEEKS, Secretary

WEATHER BUREAU
F. W. REICHELDERFER, Chief

MONTHLY WEATHER REVIEW

JAMES E. CASKEY, JR., Editor

Volume 85
Number 8

AUGUST 1957

Closed October 15, 1957
Issued November 15, 1957

PROBABILITIES OF ONE-INCH SNOWFALL THRESHOLDS FOR THE UNITED STATES

H. C. S. THOM

Office of Climatology, U. S. Weather Bureau, Washington, D. C.

[Manuscript received August 27, 1957]

ABSTRACT

Following previous work, climatological statistics and computational methods are presented for obtaining the quantiles of first one-inch 24-hour snowfall. These are employed in computing the .05, .10, .30, .90 quantiles for 164 United States and Alaskan first-order Weather Bureau stations.

1. INTRODUCTION

The one-inch snowfall threshold is defined as the first day in fall or winter on which *one inch or more* of snowfall has occurred. This is expressed as a date; i. e., by day and month. It is a typical climatological threshold variable since it expresses the time at which some critical value is passed.

The climatological analysis for such snowfall thresholds was developed by Thom [1] and applied to various values of the threshold. He found that threshold date is approximately normally distributed for years in which a threshold value occurs. If the threshold value occurs every year or with a probability approaching one, the threshold date distribution is a normal distribution on day number counted from July 1. If the threshold does not occur every year, it was found that the threshold distribution could be expressed as a mixed distribution. This is a mixture of years with no threshold occurrence and years with threshold occurrence, the threshold occurrences being further distributed as to date. This theory led to expressions for the threshold quantiles and the mean threshold date.

The one-inch threshold quantiles are given for .05, .10, .30, and .90 probability for 164 cities in the United States and Alaska. These should be useful in many types of planning problems. In particular, they will be of interest to snow tire manufacturers, snow removal equipment manufacturers, and those who are responsible for the removal of snow from streets and highways. The raw data employed in this study were originally compiled for a manufacturer of snow tires.

2. THE THRESHOLD DISTRIBUTION

The general threshold distribution function was given in [1] as

$$G(t)=pF(t)+q(t>365) \tag{1}$$

Here $G(t)$ is the probability of a threshold occurrence before date t, p is the probability of a year with a threshold occurrence, $F(t)$ is the probability of a threshold occurrence before t in years which have threshold occurrences, and $q(t>365)$ is the probability of no threshold occurrence and is included only after $F(t)$ approaches one. The non-occurrence of a threshold here is formally equivalent to the occurrence of a threshold outside the dated threshold population, or outside the 365-day year allowed for thresholds to occur and therefore not considered as an occurrence.

Although the result is the same, the threshold distribution may be developed in a somewhat different fashion as follows: According to the development above, $F(t)$ is the probability of a threshold occurring before t, hence, $1-F(t)$ is the probability of a threshold after t. We may now express the distribution function for a threshold after t as

$$H(t)=p[1-F(t)]+q. \tag{2}$$

Hence, the distribution function for a threshold before t is

$$G(t)=1-H(t)=1-p[1-F(t)]-q=pF(t) \tag{3}$$

This becomes identical with equation (1) when we add q, the probability of no threshold occurring, and meets the condition that a distribution function must approach unity as t increases without limit. Equation (3) may also be looked upon as a conditional probability; i. e., the product of the probability of a threshold occurring by the probability that it will occur before t, given that a threshold has occurred. Graphical illustrations of the frequency distribution and distribution function are given in [1]. Equation (3) will be found convenient for the computation of the quantiles.

In reference [1] the hypothesis that $F(t)$ is a normal distribution function was examined and the hypothesis of normality found to be well met by the samples studied. Similar procedures were applied in examining the normality hypothesis for this much larger sample of stations on the one-inch threshold. As was to be expected, statistical analysis showed no general significance departure from normality. Hence, we have again assumed t to be approximately normally distributed with estimated mean t and standard deviation s.

3. COMPUTATION OF THE QUANTILES

Since the quantiles are inverse functions of the variate, they may be obtained by inverting equation (3). Writing $N(t)$ for $F(t)$ to indicate a normal distribution, equation (3) becomes

$$N(t)=G(t)/p.$$

Inverting the function on the left gives

$$t=N^{-1}[G(t)/p] \tag{4}$$

In order to use the standard normal tables, t must be converted to the standardized variate $x=(t-\bar{t})/s$. Substituting this in (4) we find

$$(t-\bar{t})/s=N^{-1}[G(x)/p].$$

Hence

$$t_G=sN^{-1}[G(x)/p]+\bar{t} \tag{5}$$

where t_G is a quantile with probability $G(x)$.

Using the climatological series of one-inch thresholds the mean $\bar{t}$ and the standard deviation s were estimated in the usual fashion. Since p is the probability of such a threshold occurrence, it was estimated by the ratio of the number of years with thresholds to the total number of years of record n. These are shown for each station in table 1.

The procedure for obtaining the quantiles may be best illustrated by an example. Taking the first station in the table, Anniston, Ala., we find $\bar{t}=2/2$ (i. e., Feb. 2), $s=32.1$, and $p=0.2889$. Converting $\bar{t}$ to day number gives 217 (the exact value was 216.6). For the .05 quantile $G(x)=.05$. Substituting these values in equation (5) yields

$$t_{.05}=32.1N^{-1}(.05/.2889)+216.6$$
$$=32.1N^{-1}(.173)+216.6$$

Referring to a standard normal table and keeping in mind that .173 is a probability, we find $N^{-1}(.173)=-0.94$. Substituting this value yields

$$t_{.05}=32.1(-.94)+216.6=186.$$

Converting this day number to date we find $t_{.05}=1/2$, or January 2, which agrees with table 1. It is clear that any quantile may be readily obtained by this procedure.

It should be noted that since p is the amount of probability in the actual occurrence of a threshold, the quantile probabilities cannot exceed this amount. Hence, when the computed quantile probability exceeds p there is no entry in the table. No stations were included where the probability of a threshold occurrence was less than 0.10. Each quantile $t_{.05}$, etc., of table 1 is the date for which the probability of one inch or more in 24 hours occurring earlier in date is the quantile probability. Thus, for Burlington, Iowa, as seen in the table, the probability of a threshold occurrence before 10/23 is 0.05, before 11/2 is 0.10, before 11/21 is 0.30 and before 1/6 is 0.90. Also in other terms, the first one-inch 24-hour snowfall will occur on the average once in 20 years before 10/23, once in 10 years before 11/2, about once in 3 years before 11/21, and in nine out of ten years before 1/6.

ACKNOWLEDGMENTS

The author wishes to express thanks to Mr. C. K. Vestal for calling attention to the tabulated data, to the National Weather Records Center for fitting the distributions, and to Mr. Maurice Kasinoff for making the final calculations.

REFERENCE

1. H. C. S. Thom, "Climatological Analysis of Snowfall Thresholds," *Archiv für Meteorologie, Geophysik, und Bioklimatologie, Serie B*, vol. 8, No. 2, 1957, pp. 195–201.

TABLE 1.—*Statistics on one-inch threshold for snowfall for 164 first-order stations, listed alphabetically by states. The entries under $\bar{t}$ and t_G indicate "month/date"*

Station	$\bar{t}$	s	n	p	$t_{.05}$	$t_{.10}$	$t_{.30}$	$t_{.90}$
Anniston, Ala	2/2	32.1	45	0.2889	1/2	1/20		
Birmingham, Ala	1/24	35.3	51	.4118	12/14	12/31	2/15	
Tucson, Ariz	1/10	25.0	21	.3810	12/13	12/25	1/30	
Fort Smith, Ark	1/19	29.2	51	.7843	12/6	12/17	1/10	
Little Rock, Ark	1/15	33.2	51	.6471	11/29	12/12	1/12	
Eureka, Calif	1/23	25.9	51	.1176	1/18	2/19		
Red Bluff, Calif	1/6	18.8	51	.4118	12/15	12/24	1/18	
Denver, Colo	10/27	18.5	51	1.0000	9/26	10/3	10/17	11/19
Grand Junction, Colo	12/2	23.3	51	.9804	10/25	11/2	11/20	1/3
Pueblo, Colo	11/16	24.2	51	1.0000	10/8	10/16	11/4	12/17
Hartford, Conn	12/9	19.4	47	1.0000	11/7	11/14	11/29	1/3
New Haven, Conn	12/11	20.5	51	1.0000	11/7	11/15	11/30	1/6
Wilmington, Del	12/22	25.6	43	.9535	11/11	11/20	12/10	2/1
Atlanta, Ga	1/17	34.8	51	.2745	12/17	1/5		
Augusta, Ga	1/17	36.9	51	.1176	1/10	2/24		
Macon, Ga	1/22	37.7	51	.1569	1/5	2/5		
Boise, Idaho	12/6	21.3	51	.9804	11/1	11/9	11/25	1/4
Pocatello, Idaho	11/21	25.0	51	1.0000	10/11	10/20	11/8	12/23
Cairo, Ill	12/30	29.5	51	.9412	11/12	11/23	12/16	2/19
Chicago, Ill	12/6	18.7	51	1.0000	11/5	11/12	11/26	12/30
Moline, Ill	12/11	21.0	20	.9500	11/7	11/14	12/1	1/14
Peoria, Ill	12/12	24.5	45	1.0000	11/1	11/10	11/29	1/12
Springfield, Ill	12/17	27.8	51	1.0000	11/1	11/11	12/2	1/21
Evansville, Ind	12/24	28.5	51	.9020	11/9	11/20	12/12	3/16
Fort Wayne, Ind	12/7	23.0	40	.9750	10/31	11/8	11/26	1/9
Indianapolis, Ind	12/15	23.3	51	1.0000	11/7	11/15	12/3	1/14
Terre Haute, Ind	12/19	24.1	39	1.0000	11/9	11/18	12/6	1/19
Burlington, Iowa	12/4	25.7	49	1.0000	10/23	11/2	11/21	1/6
Charles City, Iowa	11/26	20.1	51	1.0000	10/24	10/31	11/15	12/22
Davenport, Iowa	12/8	23.8	51	1.0000	10/30	11/8	11/26	1/8
Des Moines, Iowa	12/5	21.9	51	1.0000	10/30	11/7	11/24	1/2
Dubuque, Iowa	12/1	20.2	51	1.0000	10/28	11/5	11/20	12/26
Keokuk, Iowa	12/13	22.2	47	1.0000	11/6	11/14	12/1	1/10
Sioux City, Iowa	11/24	21.1	51	1.0000	10/21	10/28	11/13	12/21
Concordia, Kans	12/15	32.8	51	.9412	10/23	11/4	11/30	2/9
Dodge City, Kans	12/10	28.9	51	.9608	10/24	11/4	11/26	1/23
Topeka, Kans	12/12	27.5	51	1.0000	10/28	11/7	11/28	1/17
Wichita, Kans	12/18	24.4	51	.9608	11/9	11/17	12/6	1/25
Lexington, Ky	12/15	25.4	51	.9804	11/3	11/12	12/2	1/19
Louisville, Ky	12/22	28.1	51	.9412	11/6	11/17	12/9	2/8
Shreveport, La	1/15	25.8	51	.3333	12/19	1/2	2/17	
Eastport, Maine	11/25	16.8	51	1.0000	10/29	11/4	11/17	12/17
Portland, Maine	11/30	14.7	51	1.0000	11/6	11/11	11/22	12/19
Baltimore, Md	12/26	30.6	51	.9804	11/6	11/17	12/10	2/7
Washington, D. C	12/22	28.9	51	1.0000	11/5	11/15	12/7	1/28
Boston, Mass	12/14	18.1	51	1.0000	11/14	11/21	12/5	1/6
Nantucket, Mass	12/25	21.6	51	1.0000	11/19	11/27	12/14	1/21
Alpena, Mich	11/17	16.4	51	1.0000	10/21	10/27	11/8	12/8
Detroit, Mich	12/1	17.1	51	1.0000	11/3	11/9	11/22	12/23
Escanaba, Mich	11/21	17.3	51	1.0000	10/24	10/30	11/12	12/13
Grand Rapids, Mich	11/21	14.3	48	1.0000	10/28	11/2	11/13	12/9
Lansing, Mich	11/22	17.0	41	1.0000	10/25	10/31	11/13	12/14
Marquette, Mich	11/2	15.3	51	1.0000	10/8	10/14	10/25	11/22
Sault Ste Marie, Mich	11/3	13.3	51	1.0000	10/12	10/17	10/27	11/20
Duluth, Minn	11/13	21.2	51	1.0000	10/9	10/17	11/2	12/10
Minneapolis, Minn	11/20	22.3	51	1.0000	10/15	10/23	11/9	12/19
Meridian, Miss	1/29	30.2	51	.2353	1/5	1/23		
Vicksburg, Miss	1/20	23.1	51	.3333	12/27	1/8	2/19	
Columbia, Mo	12/19	29.3	51	.9804	10/31	11/11	12/4	1/28
Kansas City, Mo	12/12	27.7	51	1.0000	10/27	11/6	11/27	1/16
St. Joseph, Mo	12/16	32.5	41	.9756	10/24	11/5	11/30	1/31
St. Louis, Mo	12/21	23.6	51	.9804	11/12	11/21	12/9	1/22
Springfield, Mo	12/22	29.4	51	1.0000	11/4	11/14	12/7	1/29
Billings, Mont	11/2	24.1	38	1.0000	9/24	10/3	10/21	12/3
Butte, Mont	10/10	23.4	12	1.0000	9/2	9/10	9/28	11/9
Great Falls, Mont	10/19	25.0	11	1.0000	9/8	9/17	10/6	11/20
Havre, Mont	10/29	30.5	51	1.0000	9/9	9/20	10/13	12/7
Helena, Mont	10/19	24.8	51	1.0000	9/8	9/17	10/6	11/20
Kalispell, Mont	11/14	23.1	51	1.0000	10/7	10/15	11/2	12/13
Missoula, Mont	11/24	26.6	51	.9804	10/11	10/21	11/10	12/31
Lincoln, Nebr	12/7	25.5	51	1.0000	10/26	11/4	11/24	1/8
North Platte, Nebr	11/24	27.5	51	1.0000	10/10	10/20	11/10	12/29
Omaha, Nebr	12/4	25.5	51	1.0000	10/23	11/2	11/21	1/6
Valentine, Nebr	11/22	38.0	51	1.0000	9/21	10/4	11/2	1/10
Reno, Nev	12/8	33.2	46	1.0000	10/14	10/26	11/21	1/19
Winnemucca, Nev	12/4	27.7	51	1.0000	10/20	10/27	11/20	1/8
Concord, N. H	11/26	15.6	51	1.0000	11/1	11/6	11/18	12/16
Atlantic City, N. J	1/3	27.8	51	.9608	11/19	11/29	12/20	2/15
Trenton, N. J	12/19	22.4	51	.9608	11/12	11/20	12/8	1/22
Albuquerque, N. Mex	12/24	28.3	31	.9355	11/8	11/19	12/10	2/12
Roswell, N. Mex	12/25	30.7	47	.9362	11/6	11/17	12/11	2/18
Albany, N. Y	12/2	14.1	51	1.0000	11/9	11/14	11/25	12/20
Binghamton, N. Y	11/26	15.8	51	1.0000	10/31	11/5	11/17	12/16
Buffalo, N. Y	11/19	17.6	51	1.0000	10/21	10/28	11/10	12/12
Canton, N. Y	11/13	18.6	44	1.0000	10/13	10/20	11/3	12/7
New York, N. Y	12/19	17.5	51	.9804	11/20	11/27	12/10	1/12
Oswego, N. Y	11/22	13.9	51	1.0000	10/30	11/4	11/15	12/10
Rochester, N. Y	11/21	14.5	51	1.0000	10/28	11/3	11/14	12/10
Syracuse, N. Y	11/16	13.6	49	1.0000	10/24	10/29	11/9	12/3
Asheville, N. C	12/26	30.7	49	.8980	11/8	11/19	12/13	
Charlotte, N. C	1/16	32.6	51	.6863	11/30	12/13	1/11	
Greensboro, N. C	1/7	29.1	23	.6522	11/27	12/9	1/4	
Hatteras, N. C	1/12	24.5	51	.2157	12/25	1/9		
Raleigh, N. C	1/12	30.6	51	.7451	11/28	12/9	1/5	
Wilmington, N. C	1/20	29.5	51	.2941	12/23	1/8		
Bismarck, N. Dak	11/7	26.2	51	1.0000	9/25	10/5	10/25	12/11
Devils Lake, N. Dak	11/9	20.4	46	1.0000	10/7	10/14	10/30	12/5
Fargo, N. Dak	11/17	25.1	51	1.0000	10/7	10/16	11/4	12/19
Williston, N. Dak	11/11	26.7	51	1.0000	9/28	10/8	10/28	12/15
Akron-Canton, Ohio	11/27	21.1	20	1.0000	10/23	10/31	11/16	12/24
Cincinnati, Ohio	12/16	23.5	51	.9804	11/8	11/17	12/4	1/18
Cleveland, Ohio	11/28	19.2	51	1.0000	10/27	11/3	11/18	12/22
Columbus, Ohio	12/13	25.6	51	.9804	11/1	11/11	11/30	1/18
Dayton, Ohio	12/13	26.1	40	.9750	11/1	11/10	11/30	1/19
Sandusky, Ohio	12/8	20.7	51	.9804	11/4	11/12	11/27	1/6
Toledo, Ohio	12/7	18.5	51	1.0000	11/7	11/14	11/28	12/31
Oklahoma City, Okla	1/8	31.3	51	.8627	11/20	12/1	12/26	
Tulsa, Okla	12/28	15.6	12	1.0000	12/2	12/8	12/20	1/17
Baker, Oreg	11/23	19.0	50	1.0000	10/23	10/30	11/13	12/17
Portland, Oreg	1/10	29.8	51	.7843	11/26	12/7	1/1	
Medford, Oreg	1/4	26.5	40	.6750	11/26	12/7	12/31	
Roseburg, Oreg	1/11	21.8	51	.6078	12/12	12/21	1/11	
Erie, Pa	11/13	16.2	51	1.0000	10/17	10/23	11/5	12/4
Harrisburg, Pa	12/13	20.6	51	1.0000	11/9	11/16	12/2	1/8
Philadelphia, Pa	12/22	24.1	51	1.0000	11/13	11/22	12/10	1/22
Pittsburgh, Pa	12/3	22.2	51	1.0000	10/28	11/5	11/22	1/1
Reading, Pa	12/13	18.4	47	1.0000	11/13	11/19	12/3	1/6
Scranton, Pa	12/3	18.8	51	1.0000	11/2	11/9	11/23	12/27
Block Island, R. I	12/28	24.0	51	1.0000	11/18	11/27	12/15	1/27
Providence, R. I	12/15	21.1	47	1.0000	11/10	11/18	12/4	1/11
Columbia, S. C	1/11	36.6	51	.2157	12/15	1/7		
Greenville, S. C	1/16	25.8	34	.5588	12/12	12/23	1/18	
Huron, S. Dak	11/22	26.0	51	.9804	10/11	10/20	11/9	12/28
Rapid City, S. Dak	11/8	25.7	51	1.0000	9/27	10/6	10/26	12/11
Chattanooga, Tenn	1/5	28.6	51	.6471	11/26	12/7	1/3	
Knoxville, Tenn	1/3	33.1	51	.8627	11/12	11/25	12/21	
Nashville, Tenn	1/6	34.8	51	.8431	11/13	11/26	12/25	
Abilene, Tex	1/15	31.6	51	.6471	12/1	12/14	1/12	
Amarillo, Tex	12/10	33.5	51	.9412	10/17	10/29	11/24	2/5
Austin, Tex	1/22	33.6	50	.1800	1/3	1/18		
Dallas, Tex	1/11	27.4	38	.5000	12/7	12/19	1/18	
Del Rio, Tex	1/17	23.0	45	.2000	1/1	1/17		
El Paso, Tex	1/4	27.3	51	.5490	11/29	12/11	1/8	
Fort Worth, Tex	1/13	26.0	51	.5490	12/9	12/20	1/16	
Salt Lake City, Utah	11/15	18.7	51	1.0000	10/16	10/23	11/6	12/9
Modena, Utah	11/26	25.8	50	1.0000	10/15	10/24	11/13	12/29
Burlington, Vt	11/18	14.9	45	1.0000	10/25	10/30	11/11	12/7
Northfield, Vt	11/11	17.1	43	1.0000	10/14	10/21	11/3	12/3
Cape Henry, Va	1/16	25.2	51	.7647	12/9	12/19	1/9	
Lynchburg, Va	1/2	30.8	51	.9804	11/12	11/24	12/17	2/13
Norfolk, Va	1/12	27.2	51	.8431	12/1	12/11	1/2	
Richmond, Va	1/2	28.7	51	.9216	11/17	11/28	12/20	2/28
North Head, Wash	1/17	28.2	49	.5714	12/10	12/22	1/19	
Seattle, Wash	1/2	29.3	51	.7255	11/20	12/2	12/27	
Spokane, Wash	11/27	22.1	51	1.0000	10/21	10/29	11/15	12/25
Tacoma, Wash	12/26	30.1	51	.8039	11/10	11/22	12/17	
Tatoosh Island, Wash	1/2	28.2	48	.6250	11/23	12/5	1/1	
Walla Walla, Wash	12/15	26.8	51	.9608	11/1	11/11	12/2	1/25
Yakima, Wash	12/11	23.7	32	1.0000	11/2	11/11	11/29	1/10
Elkins, W. Va	11/23	24.4	51	1.0000	10/14	10/23	11/10	12/24
Parkersburg, W. Va	12/12	25.4	51	1.0000	11/1	11/10	11/29	1/14
Green Bay, Wis	11/27	21.4	51	1.0000	10/23	10/30	11/16	12/24
La Crosse, Wis	11/26	19.7	51	1.0000	10/24	10/31	11/15	12/21
Madison, Wis	11/30	19.2	51	.9804	10/29	11/5	11/20	12/26
Milwaukee, Wis	12/3	19.5	51	1.0000	11/1	11/8	11/23	12/28
Cheyenne, Wyo	10/23	25.4	51	1.0000	9/11	9/20	10/10	11/24
Lander, Wyo	10/18	25.3	51	1.0000	9/6	9/15	10/4	11/19
Sheridan, Wyo	10/26	23.9	44	1.0000	9/17	9/25	10/13	11/25
Yellowstone Park, Wyo	10/12	18.0	37	1.0000	9/12	9/19	10/2	11/4
Anchorage, Alaska	10/26	15.8	18	1.0000	9/30	10/5	10/17	11/15
Fairbanks, Alaska	10/12	16.3	26	1.0000	9/16	9/21	10/4	11/2
Juneau, Alaska	11/9	15.4	34	1.0000	10/15	10/20	11/1	11/29
Ketchikan, Alaska	12/9	33.0	18	1.0000	10/16	10/28	11/22	1/21
Nome, Alaska	10/26	14.8	20	1.0000	10/2	10/7	10/19	11/14